Introduction

Today, natural gas is one of the most important fuels in our life and one of the principle sources of energy for many of our day to day needs and activities. According to [2], water content is removed from natural gas streams to meet sales specification or other downstream gas processes such as gas liquid recovery. In particular, water content level in natural gas must be maintained below a certain threshold so as to prevent hydrate formation and minimize corrosion in transmission pipelines.

The life time of a pipeline is governed by the rate at which corrosion occurs which is directly linked with the present of water content in gas which causes the formation of hydrates that reduces pipeline flow capacities, even leading to plugging and potential damage to process filters, valves and compressors. Gas dehydration can be achieved by using solid or liquid desiccants (adsorption or absorption respectively). The natural gas that comes from the well head contains water vapor that must be removed through dehydration process to avoid damage to the transportation facilities and to improve the market specification to end users.

The use of glycol for gas dehydration involves a regenerative process where the glycol is continually recovered for re-use in the succeeding cycles. Hence, glycol regeneration is the continuous recovery/removal of absorbed water from the absorbing glycol (rich glycol) or the dehydration of glycol for re-use in the succeeding cycles of dehydration, [1]

However, water constituent’s glycol such as Ethylene glycol (EG), di-ethylene glycol (DEG), tri-ethylene glycol (TEG) show complete mutual solubility in liquid phase due to dehydration-oxygen bonds, and their water vapour pressure are very low, KLM Technology Group (2008).

Statement of Problem

Gas dehydration process using glycol has the major problem of loss of appreciable quantity of glycol during dehydration and regeneration processes due to the effect of water constituents.

Objective

The research involves experimental investigation of effects of water on Tri-ethylene glycol (TEG) with special consideration on; density, temperature, pH, viscosity and efflux time.

Literature Review

The origin of water in natural gas can be traced to the reservoir connate water that occurs naturally with hydrocarbon. The presence of this connate water in gas gives rise to various problems during dehydration process,[6]. These problems are,

- Liquid accumulation in the wellbore
- Corrosion
- Pipeline efficiency
- Hydrate formation
- Water not needed at sales point.

According to [1], thermodynamic simulation of gas dehydration is difficult due to non-ideal liquid behavior of water and glycol mixture. According to him, the interaction is impossible to simulate with normally used thermodynamic equations of state like peng-Robinson. However, he stated that to investigate the problems with the equation of state, the water-glycol mixture is simulated in MATLAB to investigate the phase behavior of the mixture. The mixture is simulated with Peng-Robinson-Stryjek-Vera equation of state. He however, concluded that the MATLAB simulations were unsuccessful in simulating the water/glycol mixture due to the non-ideal liquid behavior of the mixture.

Physical and Chemical Properties of glycol

Physically, glycols have a similar appearance as water i.e. they are colourless, odourless, clear liquid, when compared with water, glycols have higher viscosity and specific gravity at all temperature, a high boiling point, and a low freezing point. Chemically, they are water soluble and can also act as solvents for some organic compounds.

ABSTRACT

Tri-ethylene (TEG) is used to inhibit the formation of natural gas hydrates in long transportation pipelines that convey gas from remote gas field to processing units. The degradation of glycol leads to its decomposition and reduction of its pH making it more acidic thereby, increasing its tendency to cause corrosion and subsequent blockage of production and transportation facilities. The possible effect of water on tri-ethylene glycol was ascertained in terms of changes in viscosity, pH, density and efflux time as table 1to4. Thus, the resulting effect of water on glycols (TEG) is high at room temperature and low at frozen temperature as was observed in terms of pH, viscosity and efflux time of the mixture.
Methodology
The experiment involves a Laboratory research to determine the effect of water constituents on glycols in gas dehydration process using tri-ethylene glycol. In addition, the resulting effect of the mixture will be determined with special consideration on the density, viscosity, pH and temperature at normal condition (room temperature).

Apparatus
- Pyrometer or density bottle
- Weighing balance
- Thermometer
- pH scale
- Canon U-tube viscometer (150/601B)
- Beaker
- Pure water
- Tri-ethylene glycol (TEG)
- Ice block
- Stop watch

Procedure
Determination of density using weighing balances at room temperature
- Density bottle was weighed and recorded as 24.35g
- Density bottle with pure water was weighed and recorded as 74.12g
- Density bottle with TEG was weighed and recorded as 79.61g
- Density bottle with TEG when frozen was weighed and recorded as 80.27g
- Density of Pyrex beaker (200ml) used for mixing was weighed and recorded as 102.97g
- Density of the mixture of TEG and water when frozen was weighed and recorded

The mixture was weighed to 40mL equal mixed and recorded

Determination of the temperature using thermometer
- Temperature of pure water was taken and recorded as 22˚C
- Temperature of TEG was taken and recorded as 8˚C
- Temperature of mixed volume of TEG and water when frozen was taken and recorded as obtained from the viscometer chart.

Determination of pH using pH scale
- The pH of pure water was taken and recorded as 7.1
- The pH of TEG was taken and recorded as 4.033
- The pH of the mixture of pure water and TEG at equal ratio was taken and recorded.

Determination of viscosity and measurement of the efflux time using canon u-tube viscometer (150/601b) and stop watch respectively.
- The Viscometer bath was set at 22˚C (295K)
- The thermometer was inserted on the bathe to take temperature of the bathe Fluid (Water), as a Feedback reading.
- The U-Tube that matched the Viscosity of the Fluid was selected which is Canon-U-Tube Viscometer (150/60 IB).
- The sample was suck into the U-Tube (Sample end) to the level mark (R), Clamped, and allowed to flow to level mark 1 (M1)
- It was allowed to flow to level mark 2 (M2) and the timing was immediately started.
- The timing was stopped immediately the sample reached level mark 3 (M3).
- Kinematic Viscosity; Capillary tube Constant x Efflux time in second.
- Dynamic Viscosity: Kinematic Viscosity x Density of the Sample.
- Efflux Time: This is the time it took the sample to flow from mark (M2) to mark (M3) in a Canon-U-Tube Viscometer (150/601B).

Results and Discussion
At room temperature
- Weight of pyrometer or density bottle = 24.35g
- Weight of density bottle with pure water = 74.12g
- Density of water = 74.12g-24.35g = 49.77g
- Density of TEG = 79.61g – 24.35g = 55.26g

Efflux time = 5.49mins  = 5x60+49 = 349secs
- Kinematic viscosity= Efflux time x K
  = 349secs x 0.03643251= 12.72m²/s
- Dynamic viscosity = Density x Kinematic Viscosity
  = 55.26g x 12.72 cm²/s = 702.91g/cm1s

When Teg is Freezed
- Temperature = 8˚C , PH = 4.03
- Weight of density bottle with TEG = 80.27g
- Density of TEG = 80.27g – 24.35g = 55.92g
- Efflux time = 6mins  = 6x 60 = 360secs
Results of mixed volume of glycol (TEG) and pure water when frozen

(i) It was observed that before mixture, the room temperature of pure water and TEG was the same (22°C). However when TEG was frozen, the temperature dropped to 25°C and the efflux time at 22°C was 349 secs and 360 secs at 8°C. The pH value for both pure water and TEG before mix was 7.18 and 4.03 respectively. The dynamic viscosity of TEG at 22°C and 8°C varied at 720.91 g/cm.s and 734.14 g/cm.s respectively.

(ii) It was observed that at mixed volume of 10 ml to 30 ml, that pH remained constant but decreased slowly while the dynamic viscosity keep increasing. However, the Efflux time varied at each incremental mix of the solution.

(iii) It was also observed that at 50 ml mix, there was a sharp decrease in pH.

(iv) Again at 40 ml to 80 ml, the pH decreased slowly and sharply increased with a small value. In addition, the dynamic viscosity kept moving incrementally just as the efflux time kept changing.

(v) It was also observed that as the density of the solution increased, the dynamic viscosity also increased.

From chart the range of temperature for a viscometer is between 22°C to 40°C with the corresponding viscometer constant. However, when the mixture of water and TEG was frozen, the temperature dropped from 25°C (room temperature) to 4°C (frozen temperature) and the temperatures below 22°C were obtained through regression analysis with the corresponding viscometer constant as tabulated in table.1.
(vi) It was again observed that when the mixture of TEG and water was frozen, there was a sharp drop in temperature 25°C (room temperature) to 4°C (frozen).

(vii) It was also observed that on freezing, the density, efflux time and the pH remained constant.

(viii) It was also observed that the dynamic viscosity was partially constant but increased slowly as the temperature dropped.

(ix) It was again observed that the pH of the mixture was more acidic at room temperature than when frozen.

**Discussion**

The fact that both pure water and tri-ethylene glycol has the same temperature before mix shows that the two are miscible (22°C). However, when TEG was freeze, the temperature drop to 8°C which shows why it is necessary to dry natural gas to a certain point, as humidity in natural gas can cause pipelines to freeze and create problems for end users of the natural gas. In addition the change in efflux time at 22°C and 8°C shows that the viscosity of natural gas that is humid will tend to increase due to the freezing of the pipeline and process filters.

Moreover, the pH values for both pure water and TEG at room temperature are 7.18 and 4.03 respectively. This shows that the acidic content of TEG was a bit high at room temperature and the alkaline content of water was moderate. However, when equal ratios of pure water and TEG were mixed, there was a decrease in pH from 4.03 to 3.47 downward. This shows that TEG disrupts hydrogen bonding when dissolved in water. Pure TEG freezes at about 8°C, but when mixed with water, the mixture does not readily crystallize therefore, and the freezing point of the mixture is depressed. Because of its high affinity water, TEG is a useful desiccant. Tri-ethylene glycol (TEG) is widely used to inhibit the formation of natural gas hydrates in long multiphase pipeline that convey gas from remote gas field to a gas processing facility.

Furthermore, the dynamic viscosity kept increasing as the pH decreases slowly with variation in efflux time. This shows that the dynamic viscosity of a tri-ethylene glycol (TEG) based water solution is increased compared to that of water, as a consequence, the head loss in the piping system with TEG is increased compared to clean water. Again there was a sharp drop in pH at the 50ml mix; this indicated the maximum acidic content of the mixture. This shows that as the equal volume of the mixture increase, the concentration of the solution increases, thereby increasing the acidity of the solution.

Thus, in natural gas dehydration, the more ethylene glycol is added, the more it disrupts hydrogen bond in water vapour of natural gas which bring about dehydration of water in natural gas, hence, making tri-ethylene glycol (TEG) the ideal liquid for removal of water from natural gas stream.

In addition, the sharp drop in temperature from 25°C to 4°C when the mixture of TEG and pure water was frozen indicated the effectiveness of TEG to dehydrate water in a different temperature. This has shown the reason natural gas or crude oil forms crystals when being transported through subsea pipeline due to temperature variation, hence increasing the viscosity of the fluid and subsequent blockage of pipelines.
Table 1: Temperature, viscometer constant

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However, the constant nature of the density and efflux time when the mixture was frozen indicated the ability of crude oil or natural gas to gel due to temperature change.

Finally, the dynamic viscosity when the mixture of TEG and water was frozen tended to be constant but increased as the temperature dropped. However, this laboratory experiment has shown that tri-ethylene Glycol (TEG) is the ideal desiccant for natural gas dehydration at any given temperature and that the ability of TEG to disrupt Hydrogen bond in water is high at room temperature than frozen temperature in terms of pH.

**Conclusion**

The purpose of a glycol dehydrating unit is to remove water from natural gas liquids. When produced from a reservoir, natural gas usually contain a large amount of water and is typically completely saturated or at the water dew point. This water can cause several problems for downstream processes and equipment. At low temperatures the water can either freeze in piping or as is more commonly the case form hydrates with CO₂ and hydrocarbons (mainly methane hydrates). However, from the laboratory experiment, it was the reason why the acidity of the solution kept increasing showing how water can cause corrosion and hydrate formation in a pipeline, hence Glycol dehydration units depress the hydrate formation point of the gas through water removal [8].

The degradation of glycol leads to its decomposition and reduction of its pH making it more acidic thereby, increasing its tendency to cause corrosion and subsequent blockage of production and transportation facilities. However, the possible effect of water on tri-ethylene glycol was ascertained in terms of changes in viscosity, pH, Density and efflux time as tabulated in the tables and the graphs which showed in a long run the challenges the presence of water in natural gas can bring about as mentioned earlier on.

In conclusion, the resulting effect of water on glycols (TEG) is high at room temperature and low at frozen temperature as was observed in terms of pH, viscosity and efflux time of the mixture.

**Acknowledgment**

We acknowledge all our friends and the laboratory experts at the department of petroleum and gas engineering laboratory,
University of Port Harcourt, whose contributions aided in the success of this work.

Reference
[4] Southern Alberta institute of technology energy and natural resources department (1999): Gas operations over view, pg 6, 10 and 11